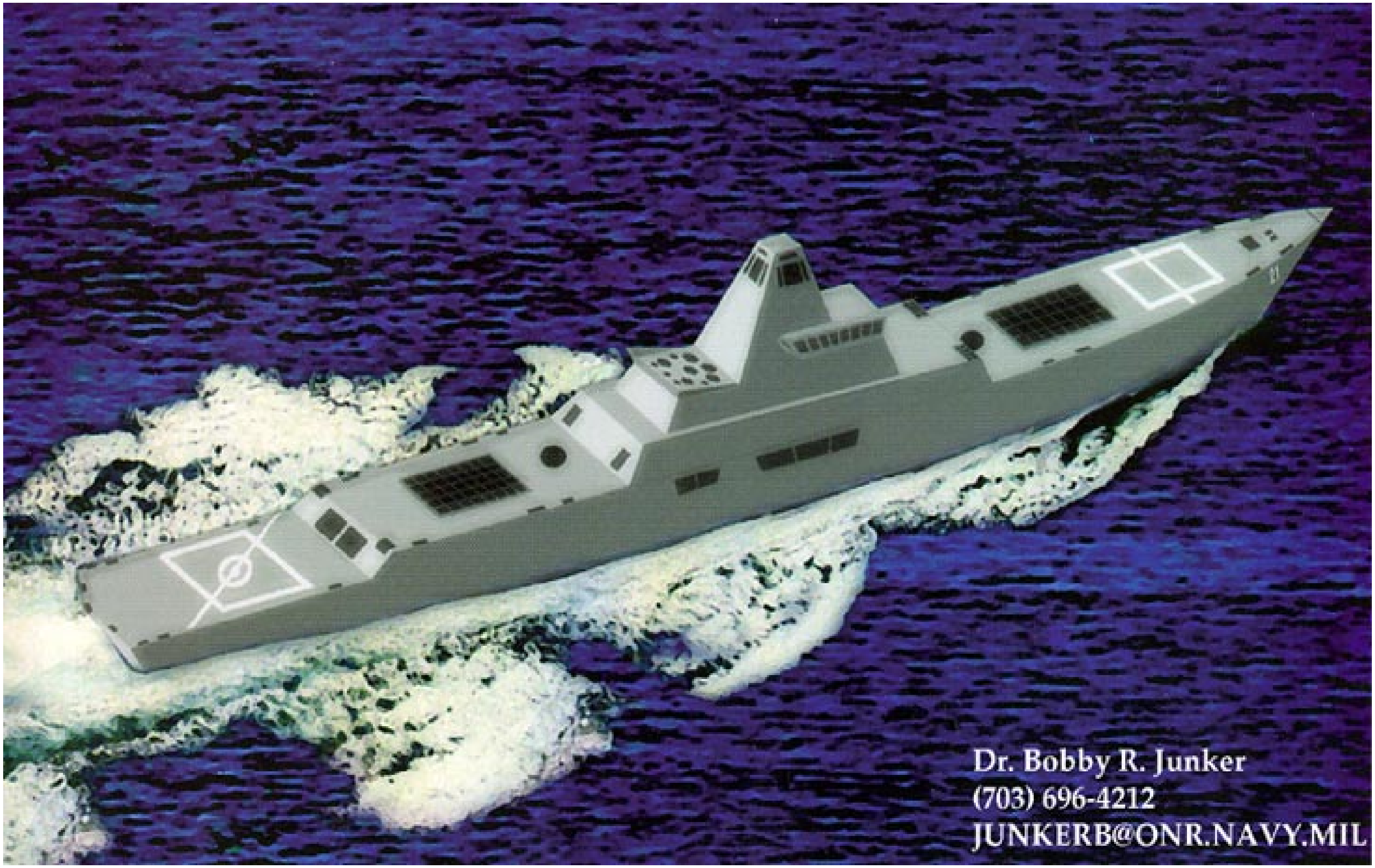
INFORMATION, ELECTRONICS AND SURVEILLANCE DEPARTMENT

ADVANCED MULTIFUNCTION RF SYSTEMS PRESENTATION TO MR. HUGH MONTGOMERY/OPNAV N91 10 JUNE 1997

DR. BOBBY R. JUNKER, Director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MULTIFUNCTION RF SYSTEMS

- **BACKGROUND**
- **NAVY PAYOFF**
- **ONR PROGRAM OBJECTIVES**
- **ONR PROGRAM FOCUS**
- **PROPOSED DEMONSTRATION SYSTEM**
- **ENABLING TECHNOLOGY PROGRAM**
- **SUMMARY**

MULTIFUNCTION RF SYSTEMS

APERTURES ON DDG-56

- **28 - COMMUNICATION ANTENNAS (BELOW 1 GHz)**
- **18 - HF-DF ANTENNAS**
- **2 - COMMUNICATION ANTENNAS (ABOVE 1 GHz)**
- **13 - RADARS/ILLUMINATORS/IFF ANTENNAS**
- **16 - EW ANTENNAS**
- **4 - OTHER ANTENNAS**

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81 - TOTAL

RF FUNCTIONAL GROUPS

Comms/Data

HF	6
VHF	6
UHF	14
EHF	2
LAMPS	4
Other	3
CEC	1

Fire Control Radar

SPG-62	3
CIWS	2

EW

SLQ-32	4

Navigation

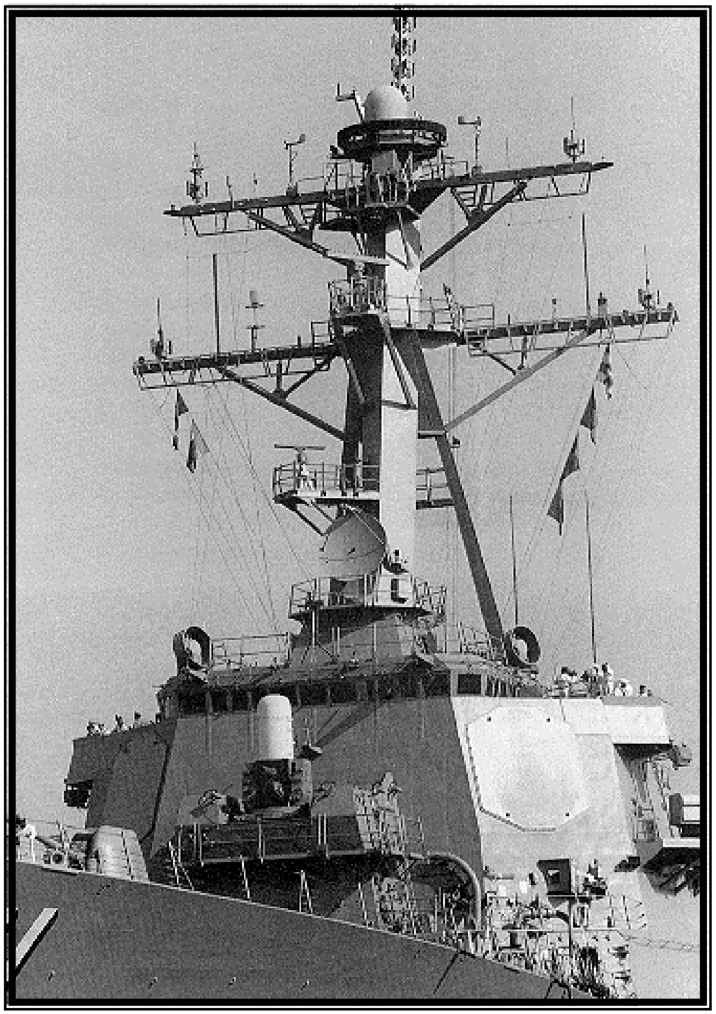
TACAN	1
GPS	2
IFF	4
Omega	1

Special

IR	1
Velocimeter	1
RADIAC	4
Combat DF	21

Search Radar

SPS-64	1
SPS-67	1
SPY-1D	4



MULTIFUNCTION RF SYSTEMS

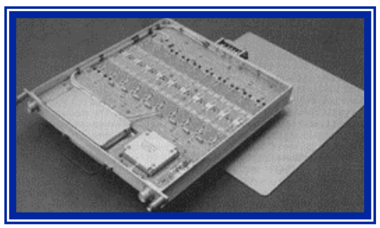
***OLD PARADIGM*:**

SEPARATE RF SYSTEMS FOR INDIVIDUAL RADAR, COMMUNICATION, AND EW (ESM & ECM) FUNCTIONS

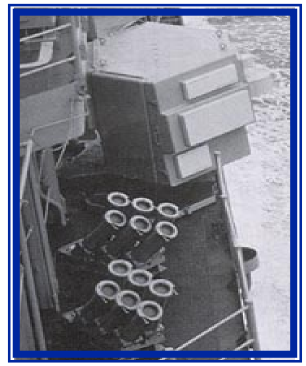
***NEW PARADIGM*:**

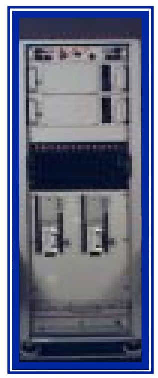
RF SYSTEMS WITH INTEGRATED RADAR, COMMUNICATION, AND EW (ESM & ECM) CAPABILITIES

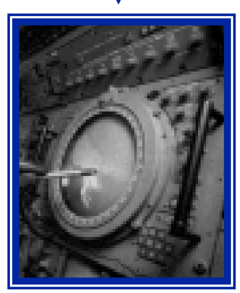
Radar



EW

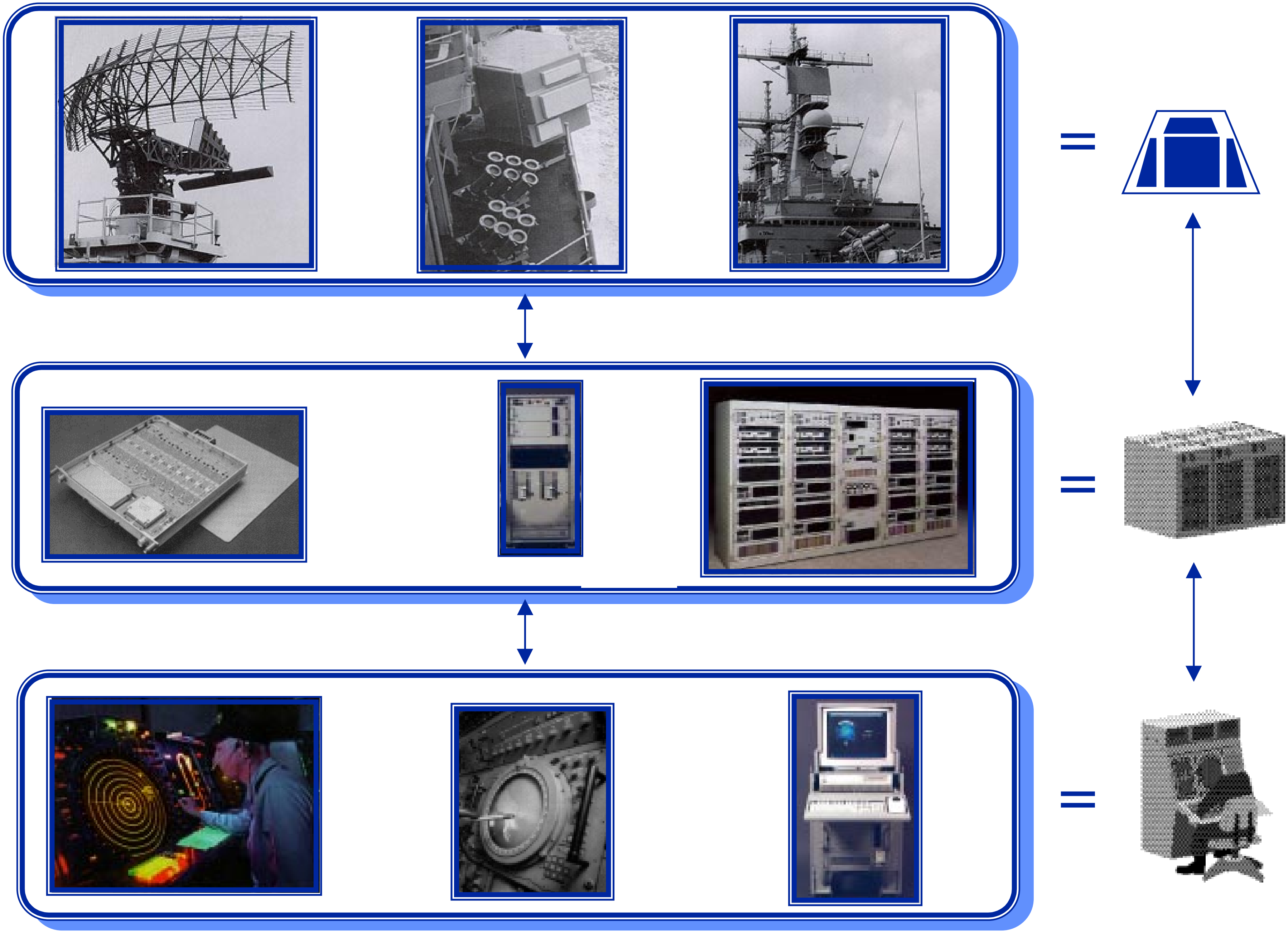






COMMS

Radar EW COMMS



MULTIFUNCTION RF SYSTEMS NAVY PAYOFF

- **COST**
  - **Reduced Life Cycle Cost and Manning Through Commonality**
- **STEALTH**
  - **Signature Reduction Built in, Not Added On**
- **LOGISTICS**
  - **Logistics Commonality**
- **CAPABILITIES**
  - **Flexibility in Resource Allocation**
  - **Enhanced Topside Design, with Reduced Topside Weight, Moment, Volume and Number of Antennas**
  - **EM Compatibility Built in, Not Arranged Out**
  - **Growth of Combat Capability Without Adding New RF Systems and Accomodation of Legacy Systems**
  - **Maintain Original RF System Performance with Reduced Blockage**
  - **Reduced Hand-off Time Between Functions**
  - **Improved Survivability**

ONR RF PROGRAM OBJECTIVES

- **DEMONSTRATE POTENTIAL MULTIFUNCTION SYSTEM ARCHITECTURES**
- **IDENTIFY KEY ENABLING TECHNOLOGIES**
- **CONDUCT RISK REDUCTION EXPERIMENTS**

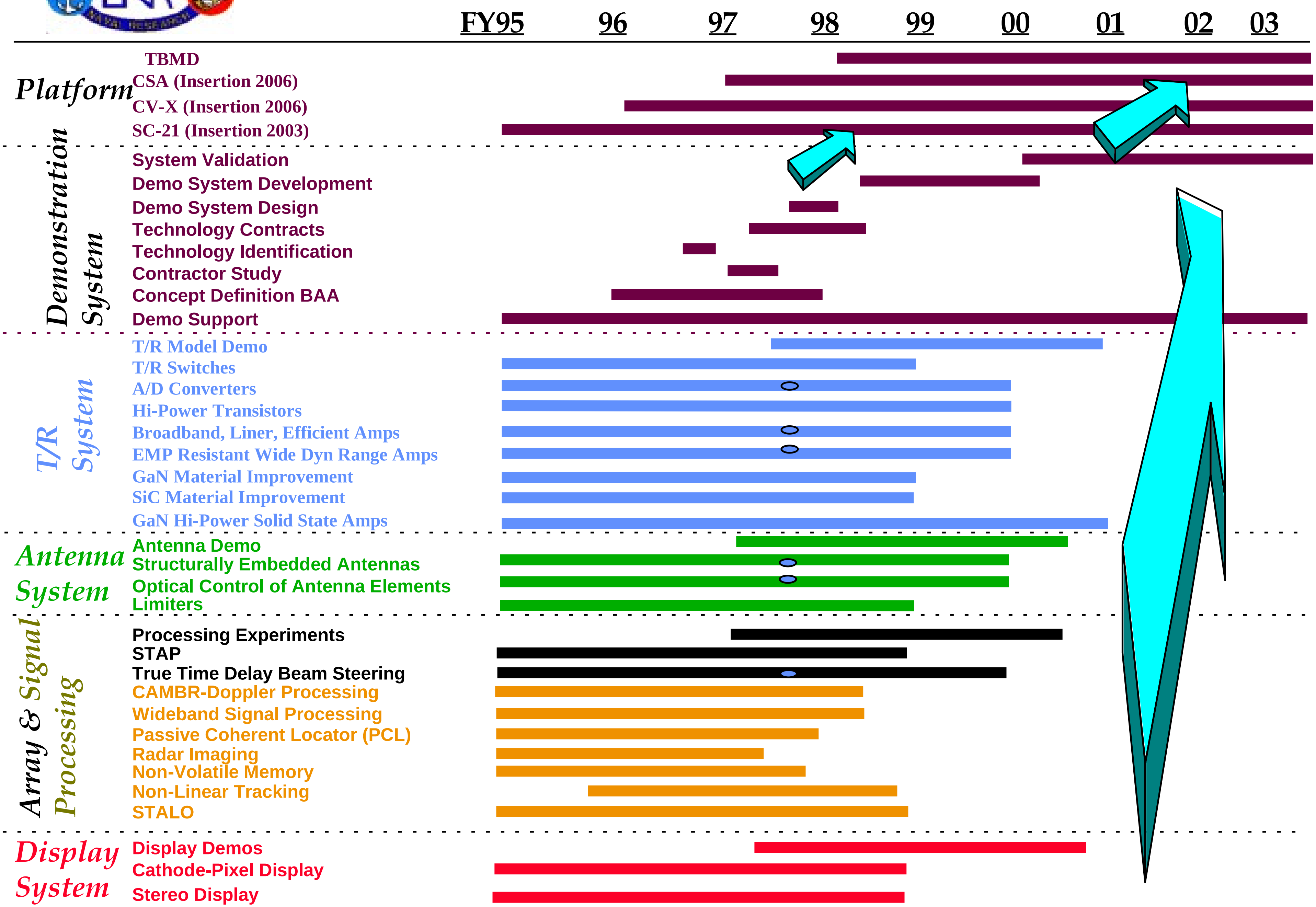
ONR PROGRAM FOCUS

- **STEALTH/COST**
  - **Minimize Stand-Alone Systems/Components & Manning**

- **BANDWIDTH**
  - **500 MHz to 20 GHz**

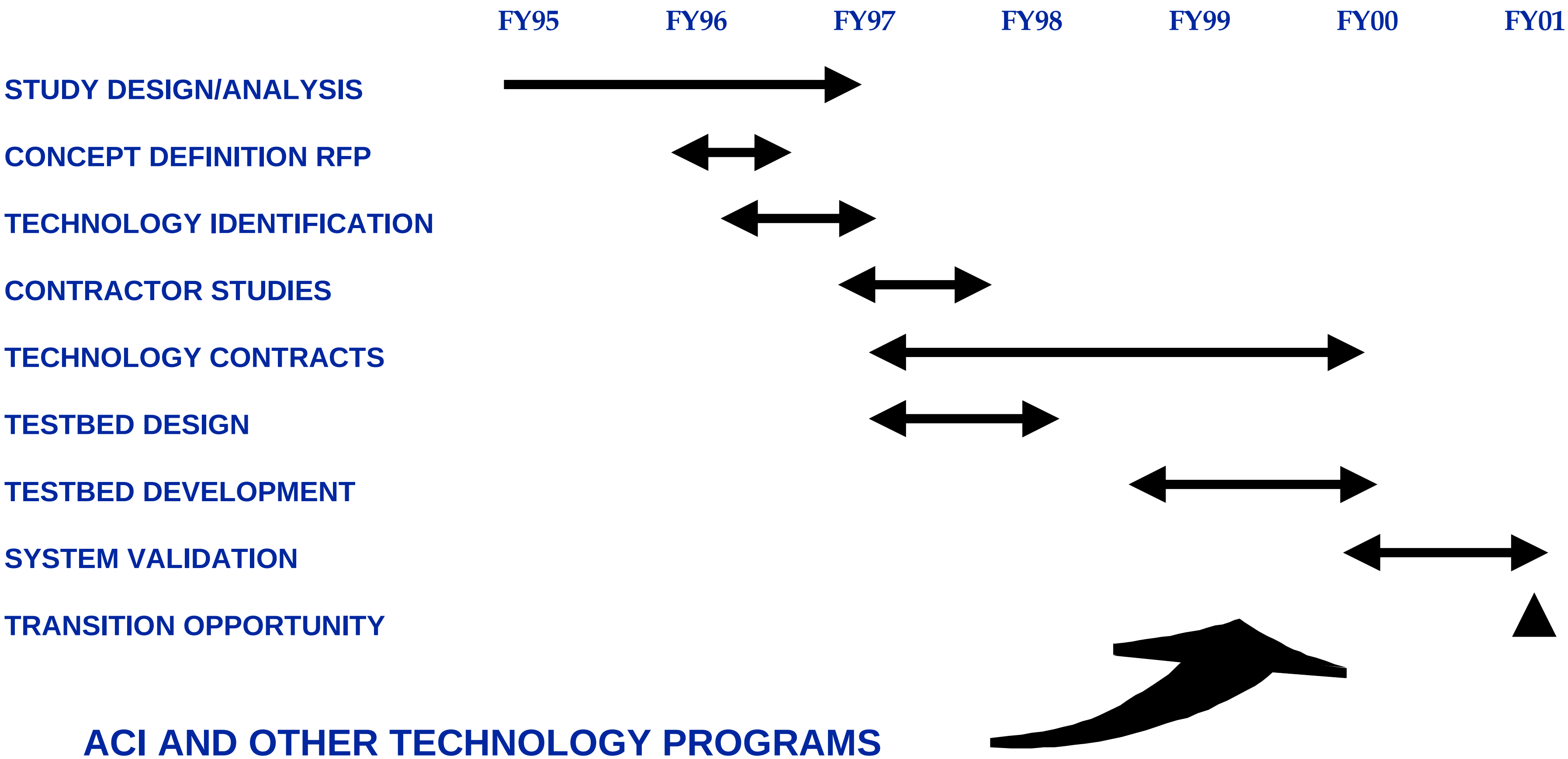
- **FUNCTIONALITY**
  - **Surveillance, Fire Control, ESM(ES), ECM(EA), Comms/Data Links**

Advanced MultiFunction RF System Management Plan



PROPOSED DEMONSTRATION SYSTEM

SYSTEMS PROGRAM EXECUTION PLAN



STATUS

Navy Lab Team Analysis Suggests Pursuit of a Dual Aperture (Transmit and Receive).

Developed Concepts

- **Provides Ever Increasing Capability**
- **Key Enabling Technologies Identified.**

One Navy Lab & Four Industry Navy Teams Developing & Analyzing System Concepts & Identifying Critical Technologies

Critical Technology Workshops Hosted to Identified Opportunities for Addressing Technical Shortfalls

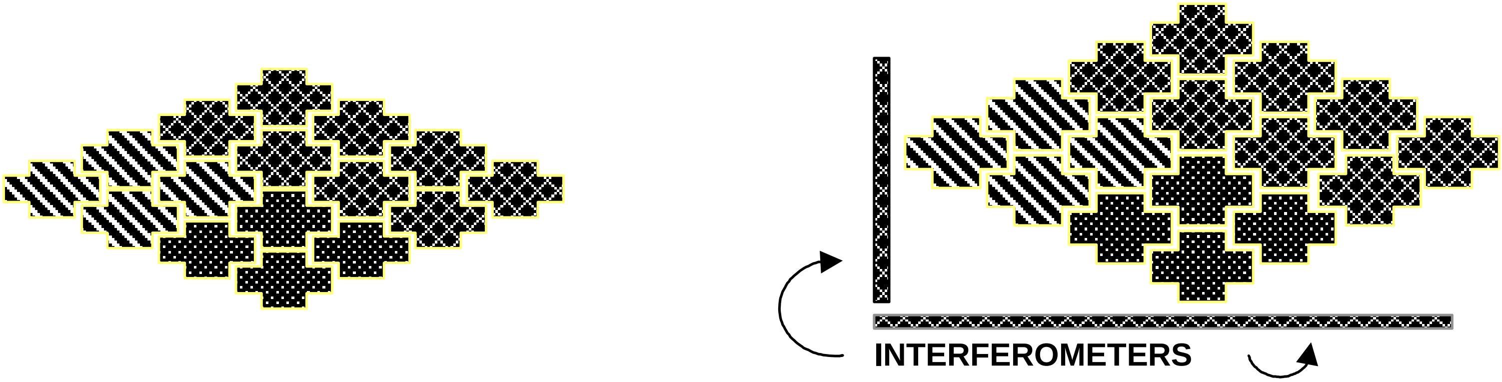
Organized Aperture Working Group Composed of Principal Acquisition Users to Provide Oversight & Guidance to Demonstration Program

MULTIFUNCTION RF SYSTEM STUDY

- Performing Organizations Include NRL, NSWC, NAWC, and NRaD.
- Initial Study Results Include:
  - Description of the Advantages of Separate Transmit and Receive Apertures
    - Lower Cost of Receive Modules Motivates Use of Larger Receive Aperture.
  - Nominal Multifunction RF Systems Concepts at Varying Levels of Complexity
    - With Dynamic Allocation of Subarrays
    - Subarrays/Arrays Transmit/Receive Some/All Signals Simultaneously.
  - Identified Critical Issues and Enabling Technologies
    - RF Amplifiers With High Power, Efficiency and Linearity.
    - High Performance: A/D Converters, STALO, Filters
    - Photonics (for Signal Distribution, Control of Phased Arrays, Etc.)
    - Wideband Radiating Elements
    - Dynamic RF Resource Allocation/Management/Optimization
    - Transmit/Receive Isolation

MULTIFUNCTION RF SYSTEMS
CONCEPT #2

TRANSMIT ARRAY   RECEIVE ARRAY



SYSTEM CONCEPT:

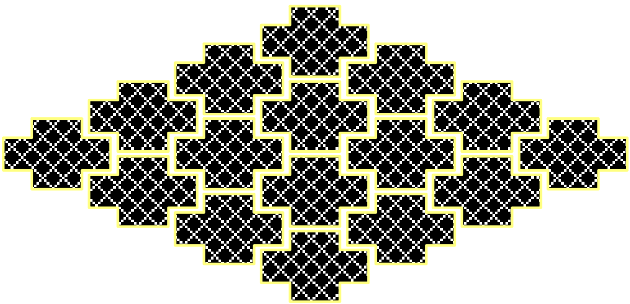
DYNAMIC ALLOCATION OF TRANSMIT SUBARRAYS
DYNAMIC ALLOCATION OF RECEIVE SUBARRAYS
- EACH RECEIVE SUBARRAY PERFORMS MULTIPLE SIMULTANEOUS FUNCTIONS (WITH CONSTRAINTS)

ENABLING TECHNOLOGIES:

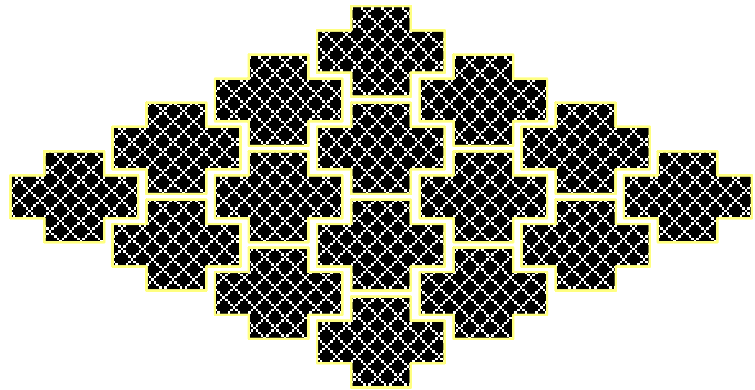
HIGH PERFORMANCE DYNAMIC FILTERS/DIPLEXERS
PRACTICAL PHOTONIC CONTROLOF PHASED ARRAYS

MULTIFUNCTION RF SYSTEMS
CONCEPT #4

TRANSMIT ARRAY



RECEIVE ARRAY



SYSTEM CONCEPT:
- TRANSMIT ARRAY TRANSMITS ALL SIGNALS
- ENTIRE RECEIVE ARRAY RECEIVES ALL SIGNALS

ENABLING TECHNOLOGIES:
- HIGH POWER LINEAR AMPLIFIERS
- HIGH PERFORMANCE A/D CONVERTERS
- DIGITAL BEAMFORMING

ONR'S ADVANCED MULTIFUNCTION RF SYSTEMS (AMRFS) INITIATIVE

ONR's AMRFS BAA (03 OCT 1996 CBD) Requested That Proposers:

- Describe Ship and Aircraft Multifunction RF Systems Concepts
- Discuss Critical Issues Such As Antenna Design, Isolation, Transmit and Receive Modules, Power Supply, Beamforming, Signal Processing, Resource Management, Etc.
- Identify Initial Demonstration of Simultaneous Multiple RF Functionality
- Develop an Open-Architecture Multifunction RF System Testbed That:
  - Operates From C Through Ku Bands
  - Demonstrates at Least Four RF Functions: Radar, ESM, ECM and Comms
  - Supports Integration and Validation of New/Emerging Technologies
- Identify Technologies and Concepts Necessary for Higher Levels of Integration.

Four Efforts (Out of Six Proposals) Have Been Initiated:

- Hughes Radar and Communication Systems (M. Burke)
- Lockheed Martin Government Electronic Systems (W. Mulqueen)
- Northrop Grumman Electronic Sensors and Systems Division (L. Williams)
- Raytheon Electronic Systems (M. Sarsione)

APERTURE WORKING GROUP

NAME	ORGANIZATION
NEIL BARON	NAVSEA
RICHARD BRITTON	PEO (SC/AP)
DOUGLAS MARKER	PEO (TAD)
STEVE VIPAVETZ	CV-X
LARRY TRIOLA	NSWCDD/PEO (SC/AP)
CHUCK CAPOSELL	NAVAIR
CAPT GARY PETERSON	CSA
MUN WON FENTON	NAWC
CDR JON SHARPE	SPAWAR
PAUL HUGHES	NRL
BOBBY R. JUNKER	ONR
WAYNE NICHOLS	ONR
CAPT OLIVER H. PERRY	ONR

ENABLING TECHNOLOGIES
STATUS AND ACCOMPLISHMENTS

WIDEBAND RF TECHNOLOGIES

Current Program Emphasis

- **Wide Bandgap Semiconductor Amplifiers - M. Yoder, ONR**
- **Hybrid Super/Semiconductor A/D Converters - D. Van Vechten, ONR**
- **Highly Stable STALOs - D. Van Vechten, ONR**
- **Highly Discriminating Wide Bandwidth Filters - D. Van Vechten, ONR**
- **Photonic Control of Phased Arrays - W. Miceli, ONR**
- **Structurally Embedded Antennas - S. Fishman, ONR**
- **Wide Bandwidth Radiating Elements - W. Miceli, S. Fishman, ONR**

Additional Technology Needs

- **Direct Digital Beamforming**
- **Dynamic RF Resource Allocation/Management/Optimization**
- **Transmit/Receive Isolation**

WIDE BANDGAP SEMICONDUCTOR AMPLIFIERS

Wide Bandgap Electronic Materials (e.g., Silicon Carbide - SiC) and Devices Have Superior Efficiency and Power Handling Capabilities

- **Traveling Wave-Controlled Electron Ejecting Cathodes**
- **Gun, Electron Injection Semiconductor Hybrid Amplifiers (GEISHA)**
- **Insulated Gate FET (IGFET) Low Power, Linear Microwave Amplifiers.**

Wide Bandgap Semiconductor Amplifiers Will Provide:

- **High Linearity, With Intermodulation Products at Least 28 dB Below Fundamental, Vice 18 dB for Conventional Solid State Amplifiers**
- **High Dynamic Range**
- **Two Decades or Greater Instantaneous Bandwidth**
- **Increase efficiency from 40% to 60% (minimum) for Conventional Linear Amplifiers**
  - **Require Less Prime Power and Cooling**
- **Longer-Life Devices With New Cathodes W/O Built-in Wear-Out Mech.**

WIDEBAND GAP TRANSISTORS

1. Materials: Silicon Carbide (SiC) and/or Gallium Nitride (GaN)

2. Device Types:
   Bipolar, Field Effect, Static Induction, & Permeable Base, & GEISHA

3. Linear, Efficient (>60%) Performance Projections:

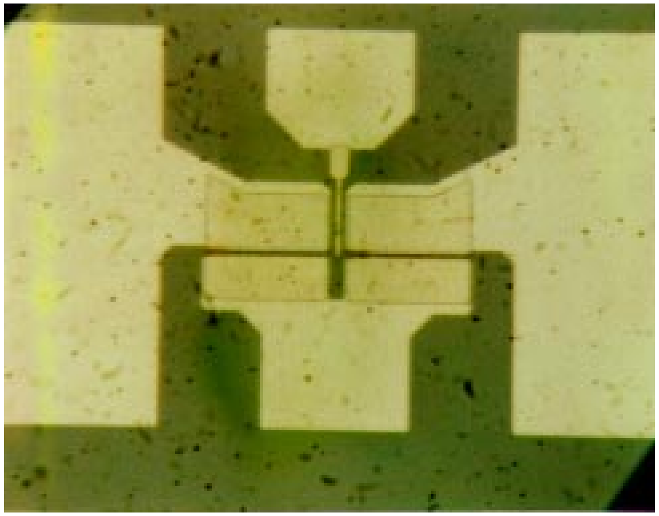
POWER OUT AT VARIOUS FREQUENCY:

UHF: 50,000 Watts

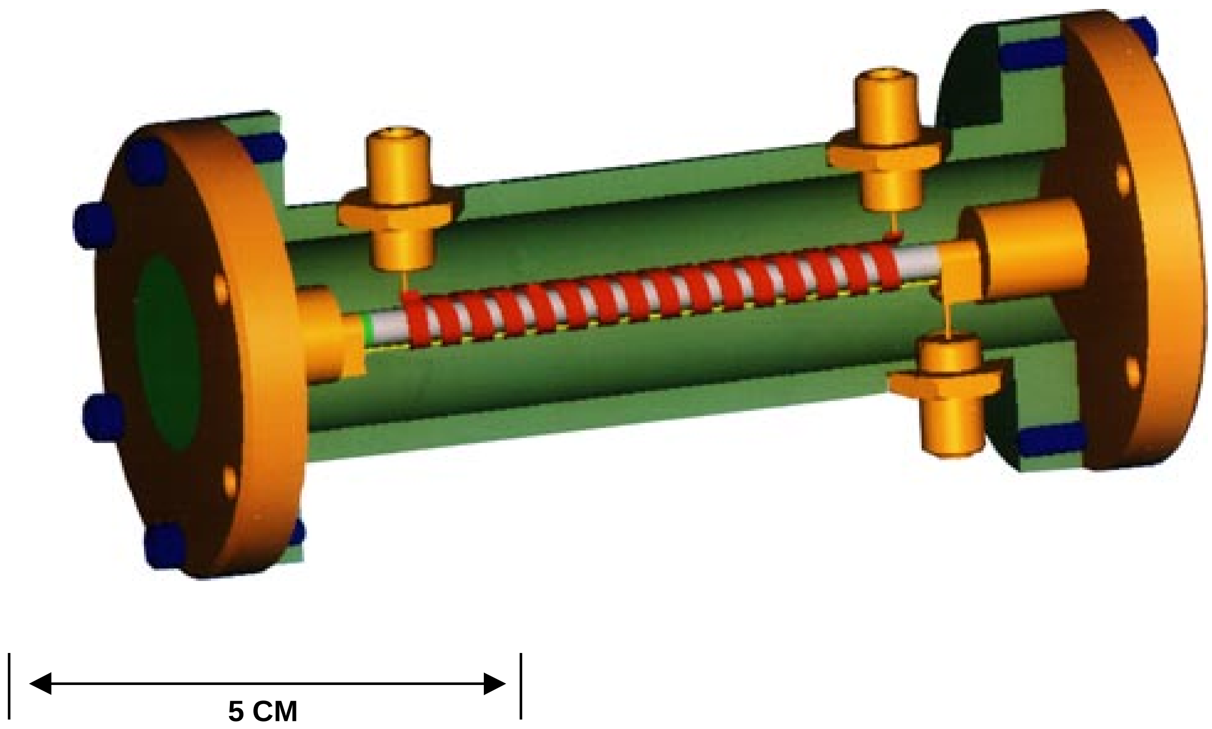
S-Band:

X-Band: > 200 Watts at 10 Ghz

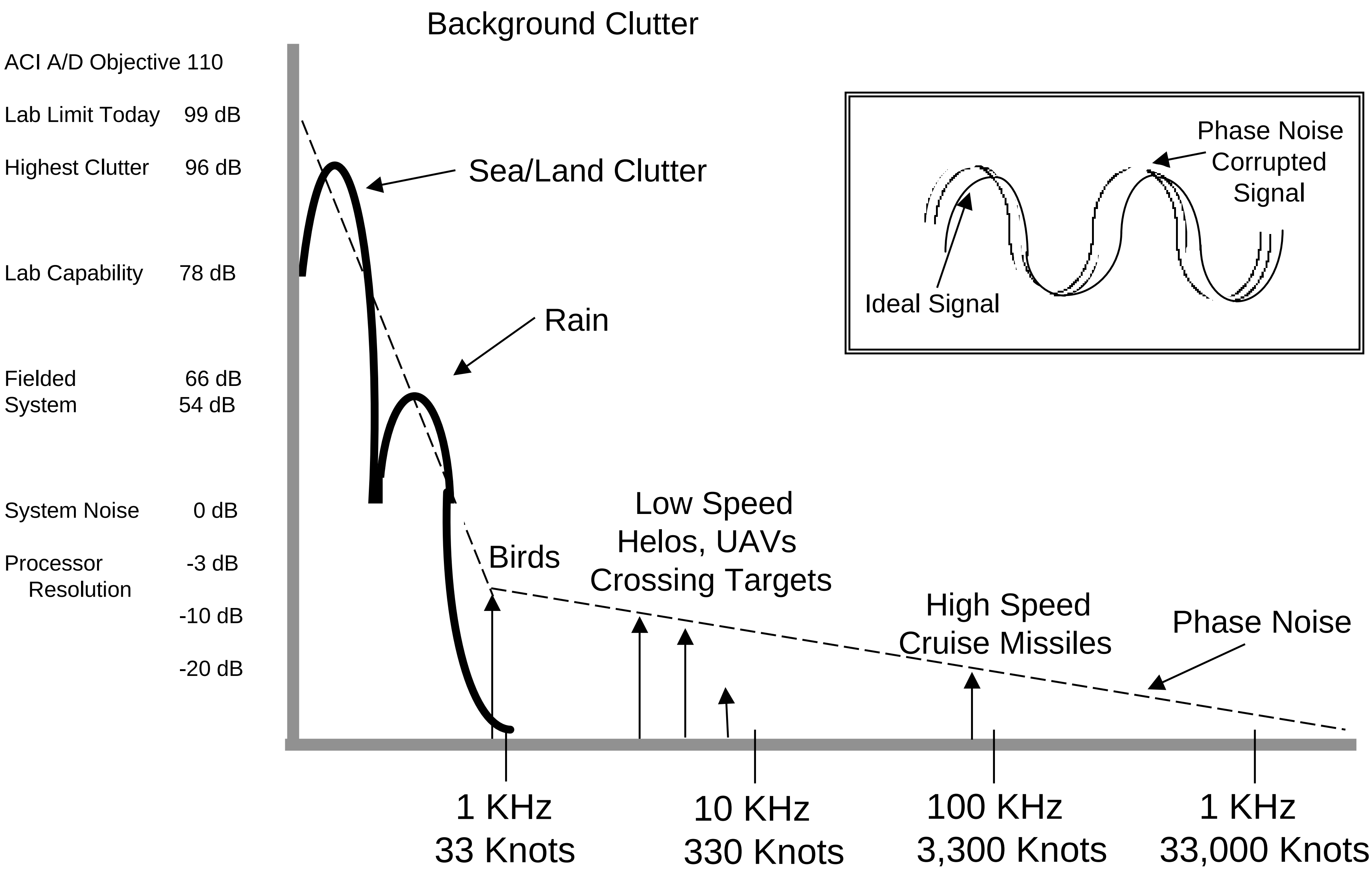
Ku-Band: > 50 Watts at 18 Ghz



Cold Cathode GEISHA First Prototype



Clutter Dynamic Range



HYBRID SUPERCONDUCTOR/SEMICONDUCTOR ANALOG-TO-DIGITAL CONVERTERS

A/D Converters with 20MHz Sampling with 20-Bit Quantization

Superconducting/Semiconducting ADCs Will Provide:

- **Enhanced Dynamic Range To Address High Clutter/Littoral Environments**
- **Digital Synthesis of Wideband Radar Waveforms**
- **Fewer Down-Conversion (STALO Mixer) Stages**
- **Ultimately, an All-Digital Receiver with Reduced Size and Weight**

HIGHLY STABLE STALOs

High T_c Superconducting Stabilized Local Oscillators

Enhanced Dynamic Range Through 10-20 dB Reduction in Noise Floor (Important in Clutter, e.g., Littoral Environment)

HIGHLY DISCRIMINATING WIDEBAND FILTERS

High T_c Superconducting Channelized Filters for Analyzing Broad Band Signals

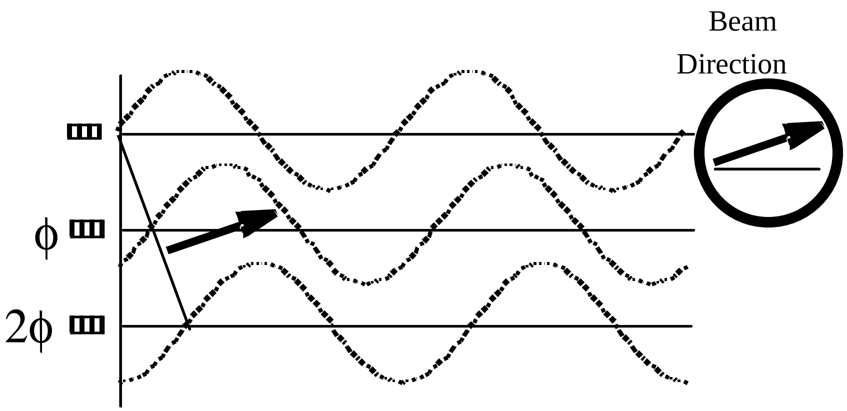
These Filters Provide:

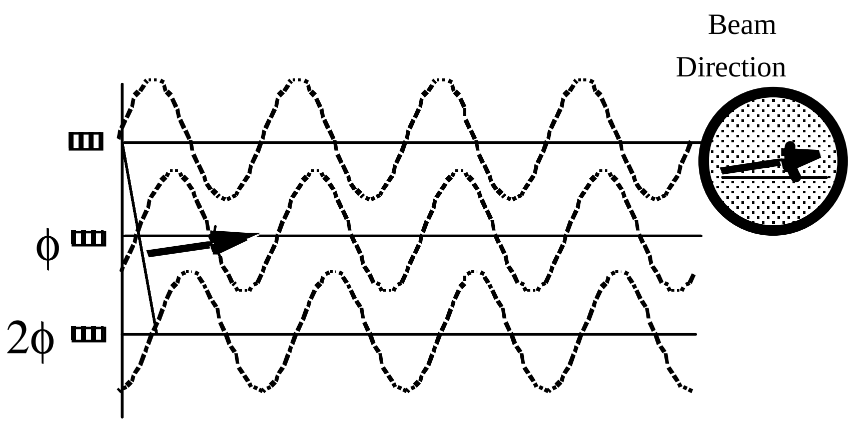
- **Improved Cut-off Properties to Reduce Out-of-Band Noise & Mitigate Jamming & Interference**
- **Reduce Size & Weight**
- **Very Low Insertion Losses**
- **Improved Linearity**

PHASE-SHIFT vs. TIME-DELAY STEERING

Frequency Effects

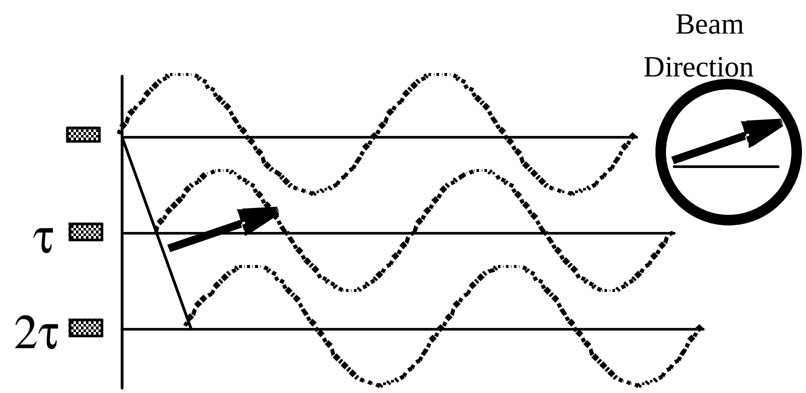
PHASE-SHIFT STEERING

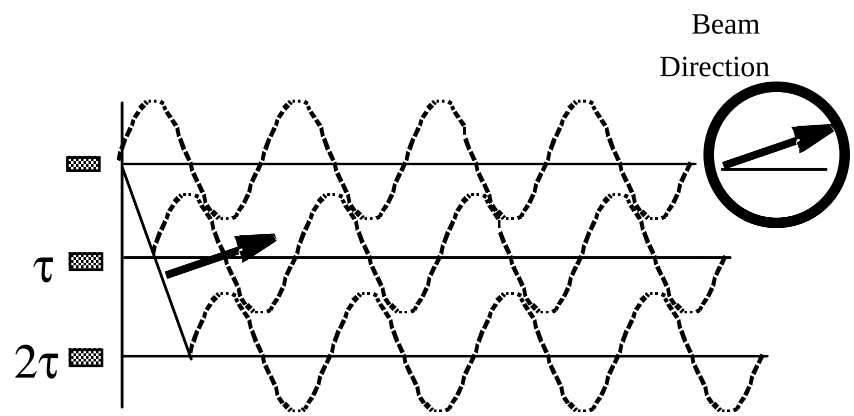




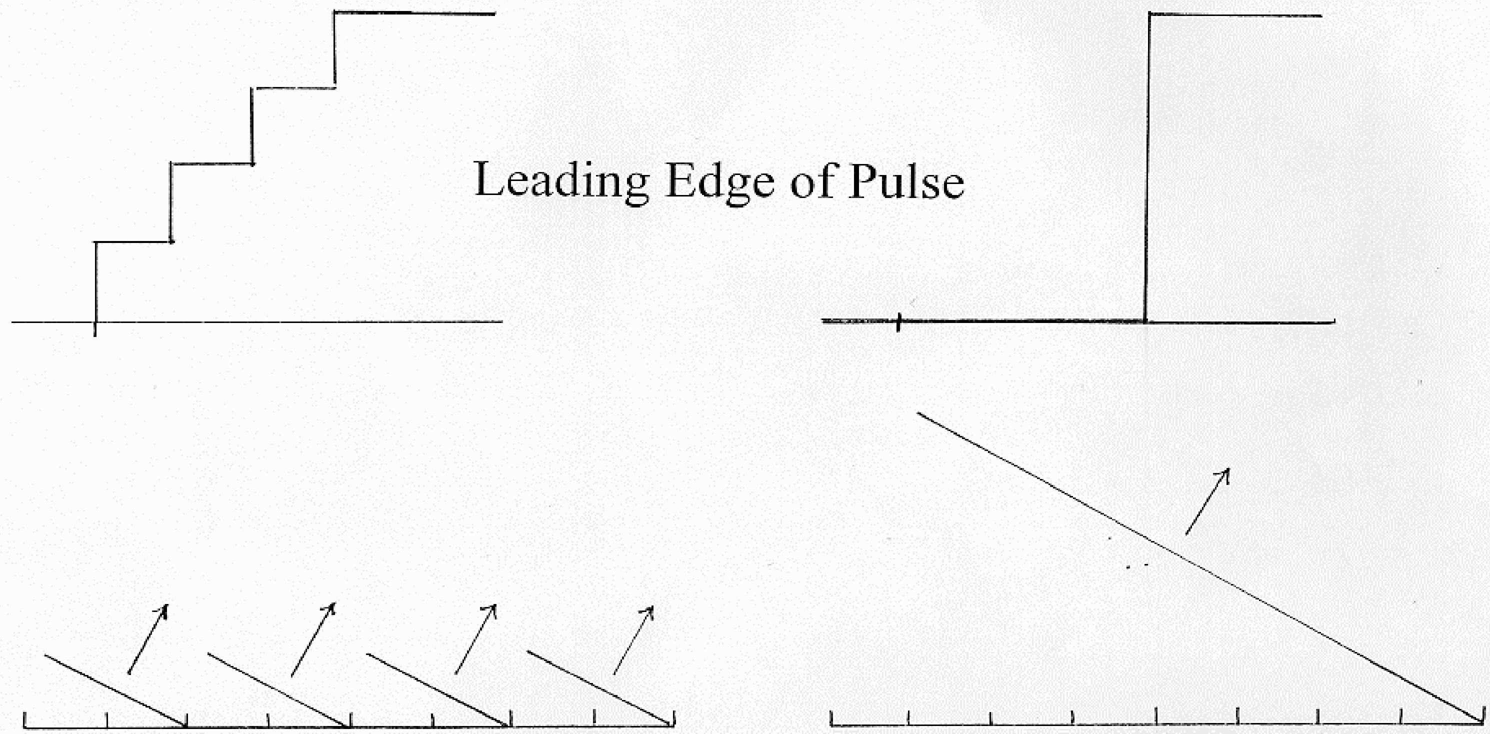
Frequency Dependent

TIME-DELAY STEERING





Frequency Dependent



Phase-Steered Beam   Time-Steered Beam

How Much Delay Is Required?

Consider a 4096 Element Array (64 by 64)

Spacing of 1/2, x @ 10 GHz = 64 x 1.5 cm = 96 cm (for end fire)

(For 60^0 off broadside, the Delay is 0.866 x 96 or 83 cm)

Depending on the Index of Refraction, the Optical Delay Line Path Must Be Capable of Being Varied From Near Zero to 33 cm

83 cm Delay / 3 x 10^{10} cm/sec = 2.77 Nanoseconds Delay

At Best, a Phase Shifter Can Supply 360^0 or 1 x

Thats 0.1 Nanosecond at 10 GHz

PHOTONIC CONTROL OF PHASED ARRAYS

Photonic Devices and Optical Techniques Provide Precise Control of the Amplitude and Phase of Microwave Signals, Enabling Rapid and Accurate Beam Steering:

- **Tunable, Single Mode Fiber Lasers**
- **Highly Dispersive Fibers with Uniform Dispersiveness Over Long Lengths**
- **Optical Techniques for Precisely Controlling Time Delays, RF Amplitude and Phase at the Antenna**

New Electro-Optic Materials (e.g., Organic Polymers) have Superior Electro-Optic Coefficients and Lower Power Requirements that Significantly Improve Light Modulator Performance

Photonic Devices and Optical Techniques Will Provide:

- **Rapid (2μsec) 2-D Beam Scanning Over Wide Angles (Greater Than 60 Degrees) Using True Time Delay Beam Steering**
- **Simultaneous Formation of Multiple Beams at Different Frequencies**
- **Reduced Cost, Weight and Size of Phased Array Systems**
- **Reduced EMI Susceptibility and Crosstalk**

Electro-Optic Light Modulators Will Provide:

- **Broadband (50 GHz) Signal Distribution to/from 100 to 1000 Antenna Elements**

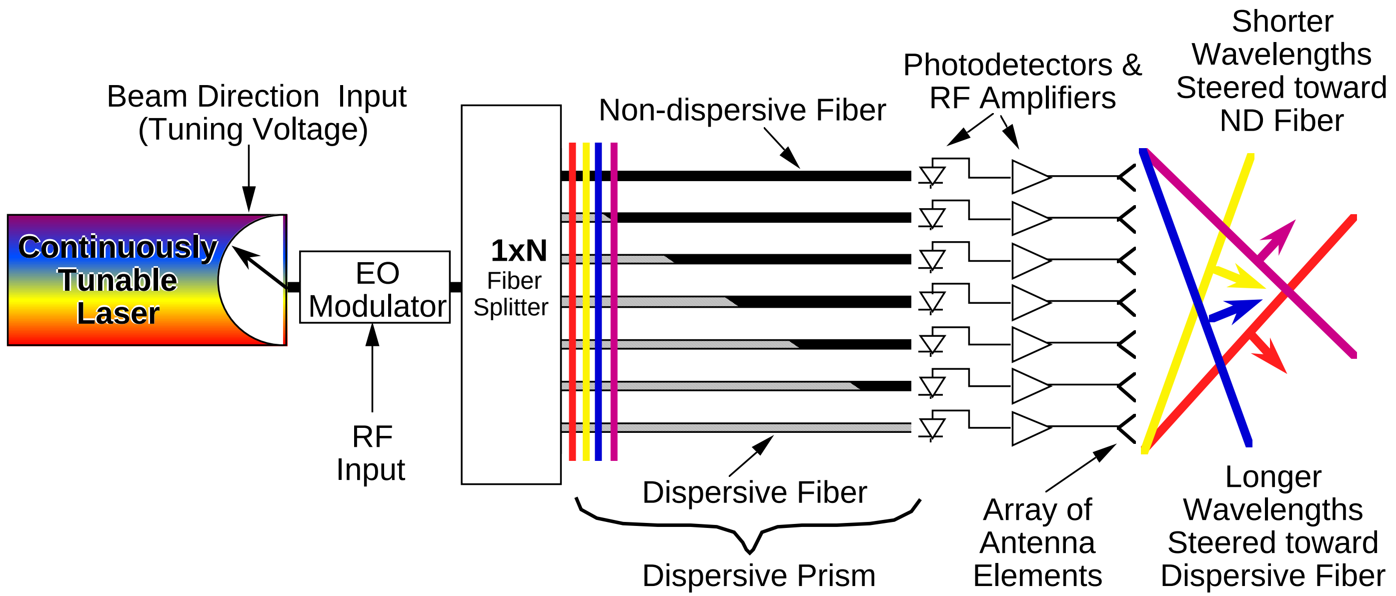
OPTICAL CONTROL OF PHASED ARRAY ANTENNAS

Use of photonic technology and optical fibers to implement time-delay steering

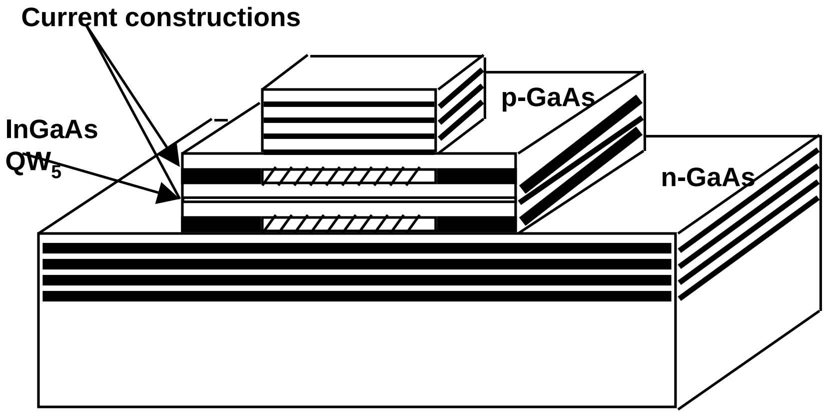
Dispersive Fiber Beamformer

Optical switching array for AEGIS dual-band phased array antenna

Photonic technology for X-band array



Ultra Efficient VCSEL



- 1000-Fold Reduction of Threshold Current
- 10^5 Lower Power Required

- High Efficency Should Permit Arraying for up to 200 Watts Output Power (IR Jammer, etc. applications)
- Low Power Permits On-Chip Transmission of Digital Data
- Overcome R-C Time Constant Problems - Increase Computer Speed Up to 50-Fold
- Basis for First Internal FM Laser (Low Noise Capability)

100 GHz Logic

A Recent "JASON" Study Shows:

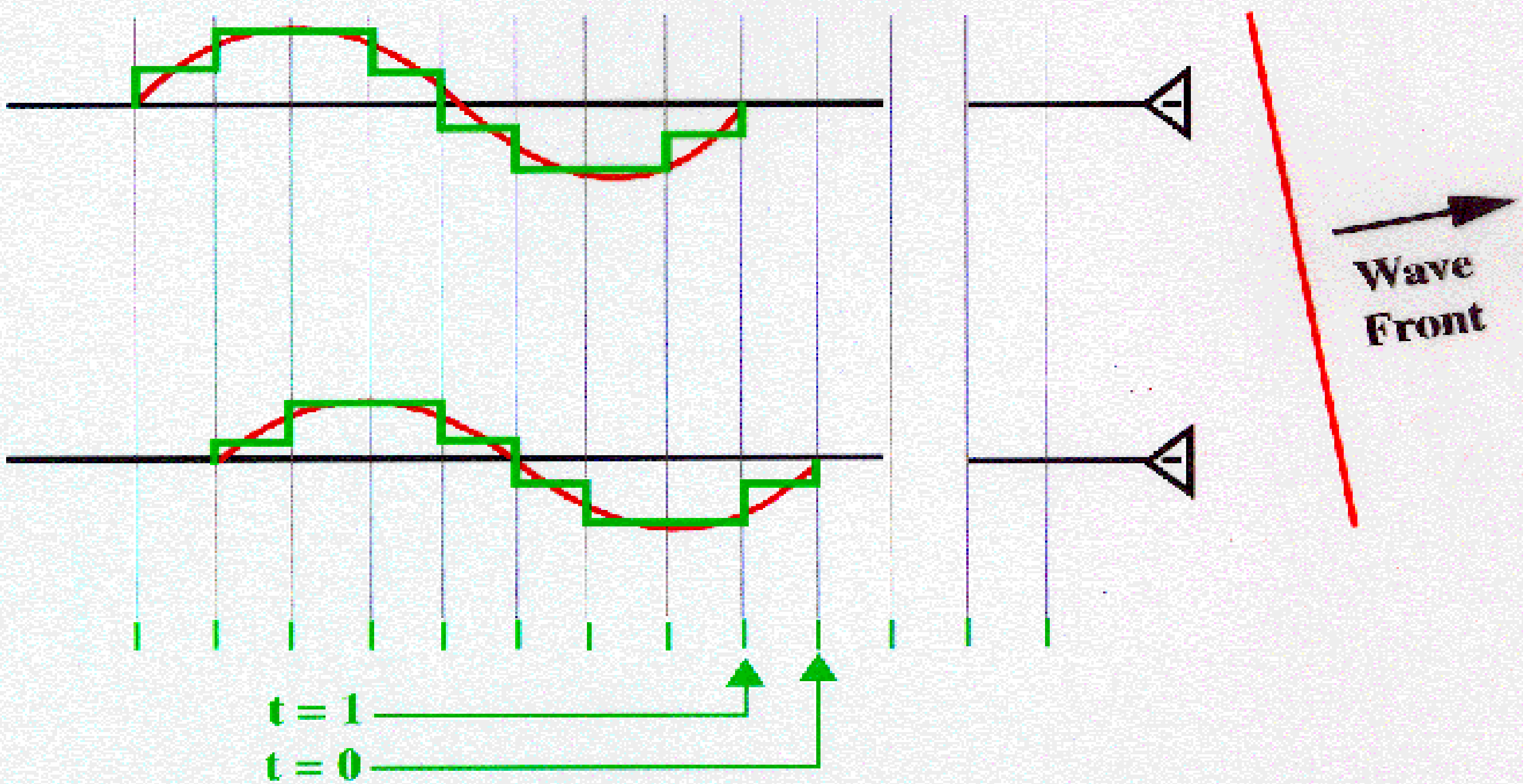
- **A Digitally Synthesized and Steered Surveillance E/M Beam Performs as Well As a True Time Delay-Steered Beam**

- **Digital Beam Synthesis and Steering Can Provide VERY Large Saving in Cost and Size Over TTD With the SAME Performance**

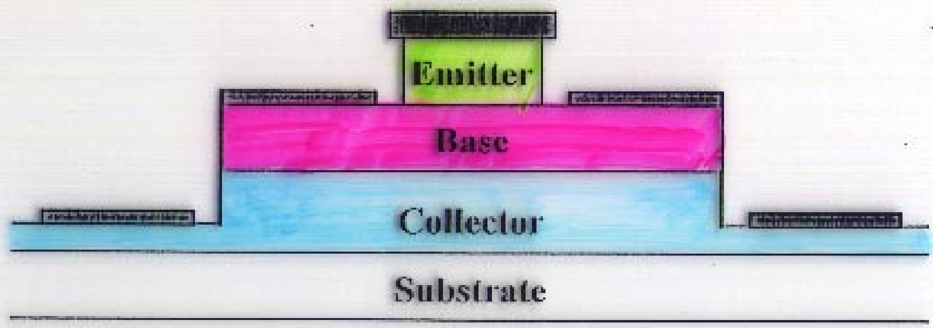
  (The advantages of TTD-steered apertures over Phase-Shift-Steered Aperatures are well known; until the advent of multifunctional systems, their cost had been prohibitive.)

  Digital Bearn Synthesis, Prs. Alvin M. Despain and John F. Vesecky; 29 April 1997

Direct Digital Synthesis (DDS)

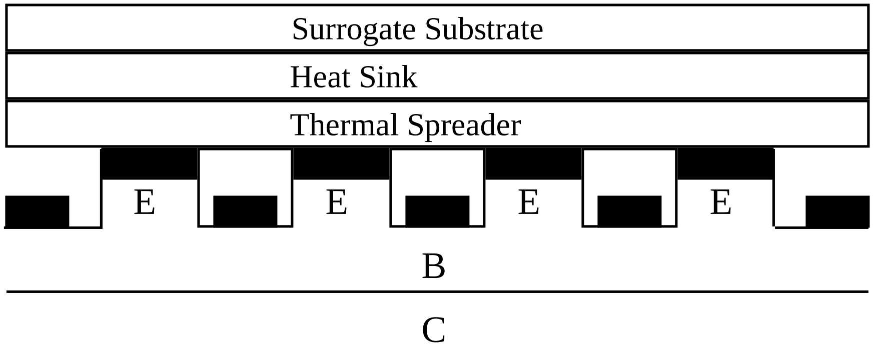


BACKGROUND - CONVENTIONAL HBT



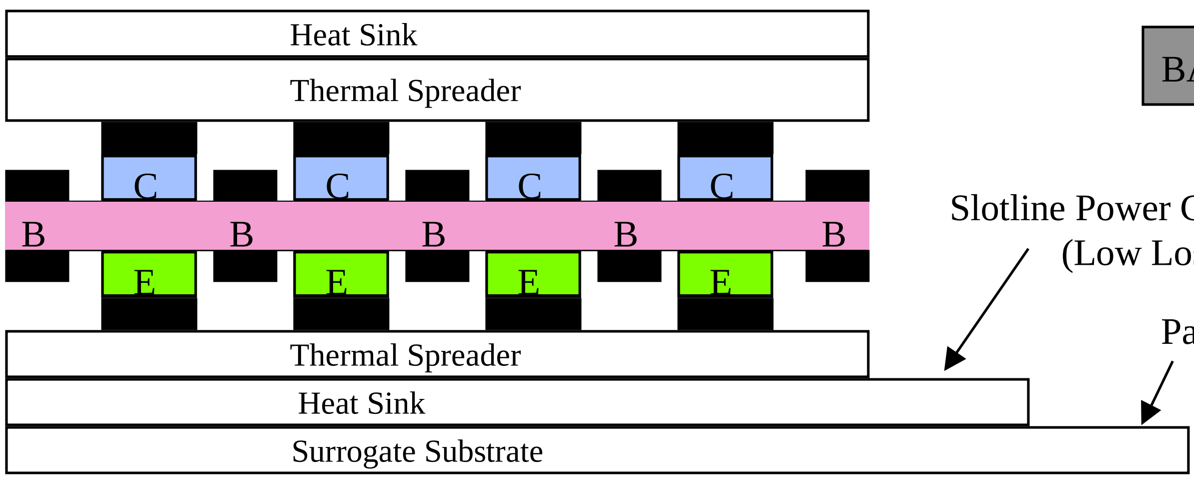
- Collector contacts "outside base contacts $\Rightarrow$ extrinsic C_{bc}
- Large C_{bc}^{ext} increases $C_{bc} \Rightarrow$ limits $f_{max} \cong \left[\frac{f_T}{8\pi R_b C_{bc}}\right]$
- C_{bc}^{ext} reduction with ion implantation not effective at high V_{bc} and only partially effective at low $V_{bc} \Rightarrow$ limits large signal performance

LOW PARASITIC HBT - MM- WAVE POWER AMPLIFIERS



FRONTSIDE PROCESSING

500 GHz Fmax
Demonstrated
April 1997!



BACKSIDE PROCESSING

Slotline Power Combining
(Low Loss)

Passive Elements Fabrication
(High Q)

Low Parasitic HBT

Source of Efficacy:

1. **Doubles Base Ohmic Contact Conductivity**
2. **Virtually Eliminates Parasitic Base - Collector Capacitance**
3. **Significantly Improves R-C Time Constants**

Low Parasitic HBT Projections

:1. **120 GHz, 2 Watts Using Conventional Semiconductors**

2. **120 GHz, 140 Watts Using Wide Bandgap Semiconductors**

3. **40 GHz , > 500 Watts With WBG Semiconductor Collector (Probably would require fusion bonding technology)**

4. **100 GHz Logic Devices for A/D Converters and For Shift-Register-Like True Time Delay Beam Steering**

   A. Possibility for Si:Ge

STRUCTURALLY EMBEDDED ANTENNAS

Addressing the Issues of Embedding Emitters & Electronic Components in Structural Composites

Materials Design and Processing Methodology for Structurally Embedded Transmit/Receive Antennas and Associated Cabling Provide:

- **Weight Reductions of up to 50%**
- **Optimum Use of Limited Platform Real-Estate**
- **Greater System Reliability Due to Increased Robustness of Electrical Connectors and Simplification of Design**
- **High Precision Fabrication Due to the Light Tolerances of Thin Film Technology**
- **Lower Fabrication Costs**
- **Improved Platform Survivability through Signature Reduction**

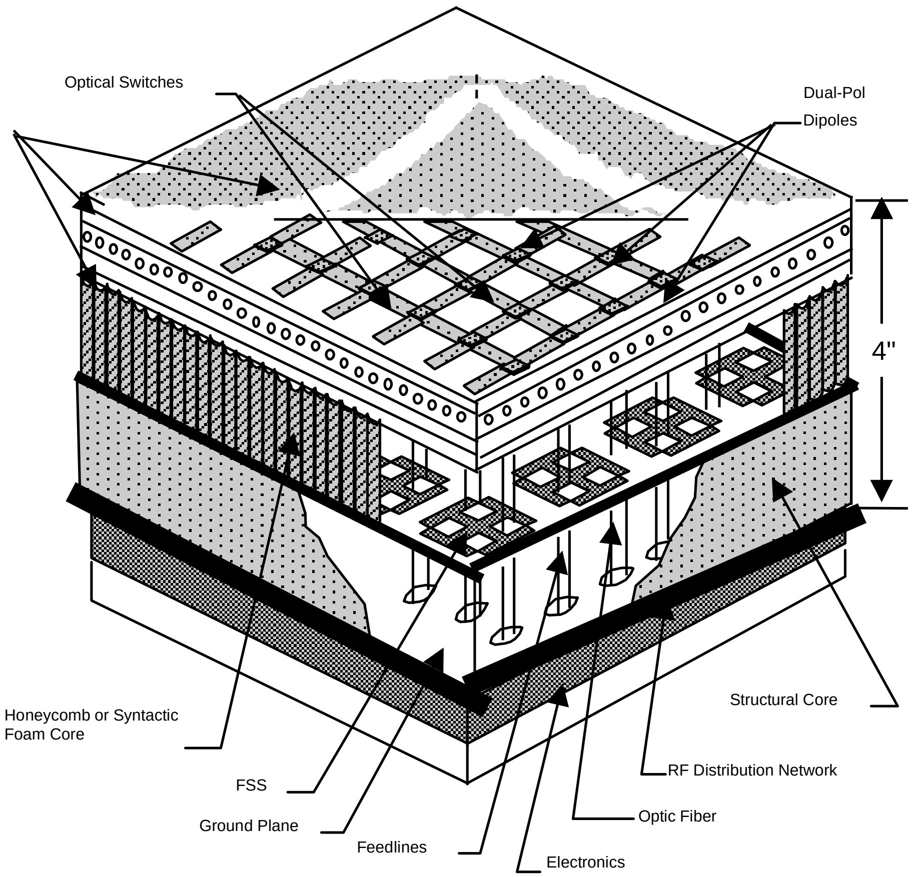
Optically Reconfigurable, Structurally Embedded Antennas

Photonic control of antennas embedded in composite materials

Optical reconfiguration of antenna dimensions & element-to-element spacing

Photoconductive antenna technology

Optically steered, wideband spiral mode microstrip conformal antennas



MULTIFUNCTION RF SYSTEMS

SUMMARY

- **PROVIDE CAPABILITY TO DYNAMICALLY ALLOCATE RF RESOURCES TO HIGHEST PRIORITY NEED**
- **SIGNIFICANTLY REDUCE ANTENNA FARMS ON NAVY PLATFORMS**
- **SIGNIFICANTLY INCREASE SURVIVABILITY BY REDUCING RADAR CROSS-SECTION**
- **INTRODUCE BENEFITS OF NEW TECHNOLOGY AT AN AFFORDABLE PRICE (WITH LIKELY COST SAVINGS OVER PRESENT STOVEPIPE SYSTEMS)**
- **PROVIDE MORE THAN AN ORDER OF MAGNITUDE INCREASE IN RANGE FOR ENGAGING THREATS (AIR PLATFORM)**